

# Orion Crew Exploration Vehicle Internal and External Lighting Analyses

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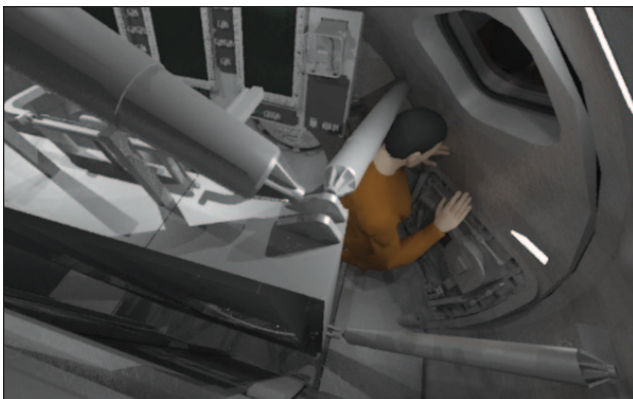
Graphics Research and Analysis Facility (GRAF) and Lighting Evaluation and Test Facility (LETF) personnel used lighting and modeling expertise and tools to complete lighting analyses for both internal and external aspects of the Orion Crew Exploration Vehicle (CEV). GRAF and LETF personnel provide an integrated approach, working closely with the end customer to understand operations and constraints, and to deliver a meaningful result.

Internal CEV analyses included assessment of the egress ladder, side hatch latch, emergency locker and displays, and control console. Actual beam axial intensity data were collected from prototype CEV light-emitting diode (LED) lights. GRAF and LETF personnel were able to begin developing accurate models using the latest Pro-E model of the interior configuration of the lights and the interior configuration. In an effort to better refine the models, these workers engaged in discussions with CEV operations personnel to sufficiently understand planned operations to consider any constraints on placement and motion of the human during operations. Based on these discussions, two scenarios were run—one with nominal power configuration and one with auxiliary power settings to cover the worst-case scenario. Researchers used a 99-percentile male model for this exercise since this is the worst case for blocking and shadowing available light. Assumptions were made about surface material and color that impact reflectance and glare based on current design.

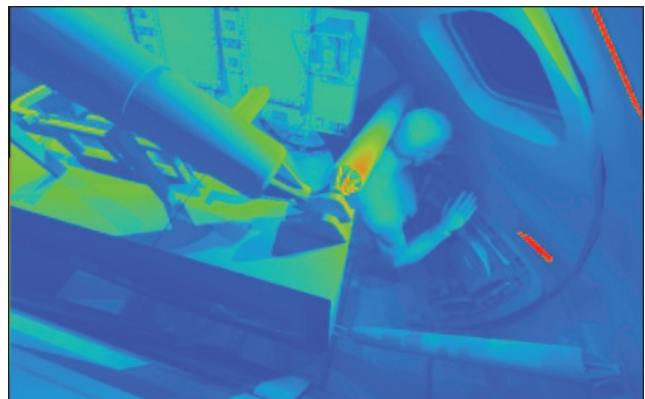
Visualizations and data were provided using Radiance software to determine actual light levels within the interior volume based on the assumptions above. A realistic picture of expected light levels (figure 1) and color-coded scaled visualizations (figure 2) were provided to illustrate the actual light-levels for each scenario. Radiance provided the predicted light levels that could then be compared against requirements and aid in design iterations.

Personnel completed an external lighting analysis to look at post-landing recovery strobe lights. A creative solution was found to establish the likelihood that the lights will be visible from all directions at a useful distance. Unlike the case in space, NASA has not established a clear-cut eye illumination threshold for operations at sea. It is expected that shadowing of the strobe lights by the structure of the spacecraft and strobe light reflections from the spacecraft surfaces will result in a complex pattern of illumination at a distance surrounding it. The analysis provides a representation of the illumination pattern and scalable values that may be compared to any desired detection threshold.

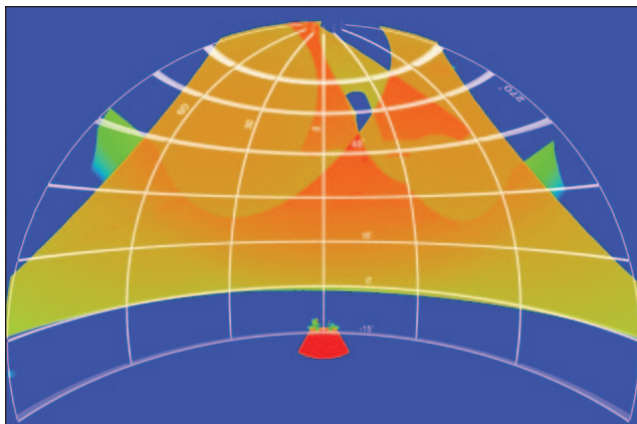
The method used for the strobe analysis involves the use of the Radiance ray-tracing program in association with other software to model the strobe lights and the reflective surfaces of the Orion spacecraft. The model also includes a hypothetical, nonreflective, black projection surface on which the illumination from the strobe lights falls. This is a spherical surface centered on and surrounding the



**Fig. 1.** Realistic image of light model.



**Fig. 2.** Color-coded scaled visualization.



**Fig. 3.** Contour maps of strobe lights reflected on projected dome.

spacecraft at a certain radial distance. This distance is great enough, compared to the spacecraft dimensions, to allow the light from each strobe to be considered as if the light is emanating from a single (common) point. This assumption allows the effective beam intensity directed from the point source to a point on the interior surface of the sphere to be calculated from the illuminance at the point and the square of the sphere's radius. The sphere's radius was chosen such that the intensity (candela) directed toward any direction is equal to 1000 times the illuminance (lux, candela/meter<sup>2</sup>) predicted at that point. Contour maps projected on the spherical surface reveal the patterns of intensity in all directions around the spacecraft (figure 3). These maps are presented as two views "looking" in opposite directions. The spherical surface is slightly larger than a hemisphere to allow for an anticipated list in the floating spacecraft.

The intensity for each of the strobe lights was again modeled as based on actual beam patterns. The beam axis was taken as the normal vector passing from/through the center of the LED array. The beam pattern was assumed to be symmetrical about the beam axis.

Command Module Uprighting System (CMUS) bags are anticipated to be a significant factor in determining the strobe light projection pattern. Analysis results illustrated

the shadowing and reflection of the strobe light beams by the bags. Since the reflective properties of the bags are not yet defined, a "bracketing" approach was taken to bound their effect on the beam patterns. The maximally reflective case was modeled using hypothetical 100% reflective white, diffuse (Lambertian) bag material. The minimally reflective case was modeled using hypothetical, totally absorbing black diffuse bag material. Illuminance simulations for each case were presented for comparison.

The creative approach of using a dome to "shine" the light on proved to be a valuable demonstration of the current design. The beam intensities derived from the spherical projection represent the peak values produced by the strobes as steady-state levels. Since the strobe light flash patterns are synchronized, separate projections for each of the four lights are not necessary. Composite patterns for the baseline three strobes and for these in combination with a notional fourth strobe are included.

Light from the strobes is attenuated from two causes: scattering from dust, salt, and water particles; and absorption of light by gasses and water vapor in the atmosphere. In the visible range of wavelengths, these losses are each equal to about 50%, resulting in a total attenuation of at least 75%. The illuminance values in the spherical projections do not include atmospheric attenuation.

Results of the analyses showed that the intensity of the light reflected on the CMUS bags is insignificant in comparison to direct-path strobe light. The strobe lights are much more visible from the 0-degree side than the 180-degree side, mainly due to shadowing by the CMUS bags. Intensity values given should be derated by 75% to allow for atmospheric scattering and absorption. The GRAF/LETF was also able to provide some alternative strobe light positions that will improve the results and visibility of the vehicle for recovery.